FROM MODEL ROCKETS TO SPACEWALKS: AN ASTRONAUT PHYSICIAN'S JOURNEY AND THE SCIENCE OF THE UNITED STATES' SPACE PROGRAM*

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ABSTRACT

From simple childhood dreams to their fulfillment, this presentation chronicles the author's life journey from young model rocketeer through his medical training and eventual career as a NASA astronaut. Over the course of four Space Shuttle flights and a cumulative 6 weeks in space, including 20 hours of Extravehicular Activity (EVA, or spacewalking), this article describes a wide range of activities and scientific payloads that are representative of the unique and valuable science that can be accomplished in the microgravity of space. NASA's efforts to develop inspection and repair capabilities in the aftermath of the Columbia tragedy are also covered, as are the nation's plans for returning to the Moon and continuing on to Mars as part of the Vision for Space Exploration (VSE).

Introduction

As a seven year old boy, I watched in awe along with the rest of the world as humans first left footprints on the lunar surface. The son of an aerospace engineer who helped rocket the crew of Apollo 11 to their unimaginable destination, I grew up with an inner drive to one day also make my passage to space. I was similarly drawn to medicine as a means to help others, and as a field with many challenges and opportunities. As I pursued my education, other interests certainly came and went, but the desire to explore and to be involved in scientific discovery remained a constant. With the advent of the Space Shuttle program, which first flew in 1981, there became a need for scientists and engineers in a variety of fields related to space science to join the ranks of astronauts: astrophysicists, chemical engineers, computer scientists, aeronautical engineers, material scientists, physiologists

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and physicians. The synergy of medicine, the physiologic research I was involved with, and spaceflight was a natural, and led to my eventual selection to the Astronaut Corps in 1992. Over the course of four spaceflights, my roles and responsibilities have included medical care and biomedical science, but have extended far beyond to many other areas of science and operations. These experiences offer insight into the breadth and importance of our nation's current and future space explorations.

Education, Training and Flight Chronology

Human physiology taken to its extremes, be they high altitudes, the extremes of temperature, the depths of the oceans or the unknowns of space travel has always been a fascination of mine. Applying to medical school and becoming a physician was a natural choice for someone with these interests, but the opportunity to go to a medical school within driving distance of a major NASA field center—the NASA Ames Research Center—was simple good fortune. Benefiting greatly from wonderful mentors in experimental physiology, I began studies of microvascular fluid shifts that occur in the weightlessness of space (1), and also began to design exercise hardware to counteract the deleterious affects of 0-G inactivity on the "antigravity" musculoskeletal system (2). The marriage of medical science and space exploration became all-apparent to me, and it certainly rekindled my childhood aspirations to become an astronaut.

My training fortuitously took me to the Brigham and Women's Hospital in Boston, MA, for a year of medical internship (Figure 1). During this memorable but often sleepless year, I was a subject in Drs. Wolf's and Czeisler's seminal study on housestaff fatigue, investigating cognitive performance over the course of the call cycle using ambulatory electroencephalography (3). Years later, I would again have the opportunity to work with one of the principle investigators (Dr. Charles Czeisler) using very similar gear, although this time it would be to study the effects of space travel on sleep patterns.

While an Emergency Medicine resident physician in training in Denver, Colorado, I received word that I would begin training as an astronaut candidate in August 1992. The intense but exciting yearlong training program took my "class" of 24 scientists, engineers, pilots and physicians through the breadth of disciplines that comprise the space program: Space Shuttle systems and simulations, skills training in robotics and EVA, flight training in NASA's T-38 aircraft, space life sciences, material science, geology, oceanography, meteorology, global

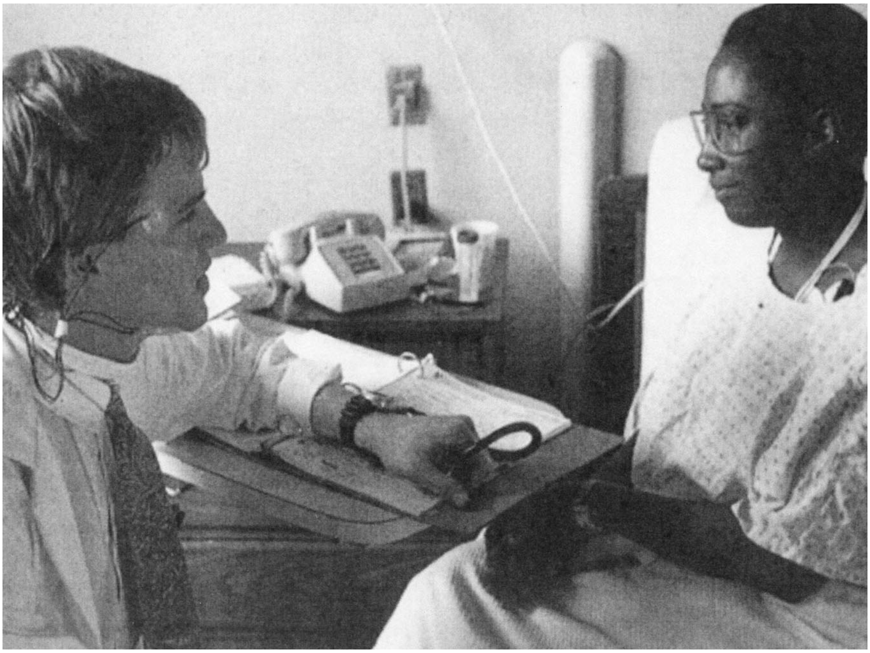

FIG. 1. Dr. Scott Parazynski, medical intern at the Brigham and Women's Hospital, Boston, MA, shown wearing an ambulatory EEG monitor while caring for a patient (1990).

environmental change monitoring, astronomy and celestial navigation to name just a few. Following completion of this initial training, our group—the fourteenth group of astronauts selected by NASA since the original seven Mercury astronauts—was eligible for spaceflight assignment.

STS-66 aboard the Space Shuttle *Atlantis* was designated ATLAS-3, shorthand for the third atmospheric laboratory flight dedicated to atmospheric study. A joint NASA-European Space Agency satellite named CRISTA-SPAS was deployed into space using the Shuttle's robotic arm for a 9 day free-flight, and then retrieved for return to earth. A cryogenically cooled telescope and spectrometers aboard the satellite were complementary to the other sensors on the ATLAS laboratory pallet in the cargo bay of *Atlantis*. A wealth of data was collected on the global distribution of protective ozone in the upper reaches of our atmosphere, as well as the complex chemistry involved in its fluorocarbon-driven destruction (4,5). In addition to the atmospheric science focus on the flight, many secondary payloads were flown, including a flight test of an exercise device I had helped develop for long duration spaceflight: the so-called Interlimb Resistance Device allowed us to exercise one side of the body against the other, making for a very effective exercise while also being very small and low mass.

STS-86, also aboard the Space Shuttle *Atlantis*, traveled to the Russian Space Station *Mir* at a critical time in the joint Shuttle-Mir program. In the months preceding our flight, a nearly fatal fire within the complex had compromised onboard environmental systems. Soon thereafter a collision between a *Progress* resupply spacecraft and the station had resulted in depressurization of the *Spektr* laboratory module. Our mission of joint science and crew transfer (delivering astronaut Dr. David Wolf and returning Dr. Michael Foale to earth) became more operationally complex. Among the repair hardware we delivered to *Mir*, I took a special solar array cap outside on a spacewalk for possible future use in on-orbit repair (6) of the leaky module. Other objectives of the spacewalk included evaluation of interoperable tools for use in both US and Russian EVA suits, and a flight test of the Simplified Aid for EVA Rescue, or SAFER—essentially a jet-driven "parachute" should an EVA astronaut become detached from his or her spacecraft. My Russian spacewalking partner, Colonel Vladimir Titov, and I retrieved several environmental sampling devices left outside on a prior spacewalk. [These experiments included aerogels, more recently used in the Stardust robotic sample return from Comet Wild-2.]

STS-95 aboard the Space Shuttle *Discovery* was a highly ambitious and successful mission with over 83 scientific payloads across a variety of disciplines. I had the honor of flying with one of my boyhood heroes, Senator John Glenn, who was aboard to participate in the study of the aging process (Figure 2). The physiological adaptations that occur during spaceflight, even to much younger astronauts, closely parallel those changes seen in the normal aging process: loss of bone calcium and structure, weakening of the postural muscles, cardiovascular deconditioning and orthostatic intolerance, sleep disturbances (7,8) and neurovestibular issues. In addition to these life science objectives, comparing age-related differences in adaptation to 0-G and readaptation to earth's 1-G, numerous fluid physics, biology and material science experiments were contained in our Spacehab module in the cargo bay. Also during the flight, a solar observing satellite called Spartan was deployed using the robotic arm for a 2 day free-flight, and then retrieved for return to earth. The satellite performed sensitive measures of the solar corona—essentially the sun's atmosphere—as these are of fundamental interest to solar physicists as well as those involved in global satellite communications (9). Of note, the mission was flown at a very high orbital altitude to support a cargo bay flight test of an

FIG. 2. Senator John Glenn instrumented for sleep, wearing EEG, ECG, pulse oximetry, nasal end tidal CO2 and pulmonary expansion sensors.

advanced cooling system that would be installed on the next Hubble Space Telescope servicing mission.

STS-100 aboard the Space Shuttle *Endeavour* targeted the new International Space Station (ISS), with the primary objective of installing the second generation Canadian-built robotic arm via EVA (Figure 3). Over the course of two 7+ hour spacewalks, my Canadian EVA partner, Colonel Chris Hadfield, and I assembled and wired the novel *Canadarm2*, which now serves as the main work platform for all ISS assembly and maintenance tasks (10). A major resupply of the ISS was also accomplished by robotically installing an Italian-built module called *Raphaello*. Major life, biological and material science facilities were also transferred during the mission. Due to a computer failure aboard the ISS, our crew extended our stay one day to assist in repair and general maintenance.

The tragic loss of the STS-107/*Columbia* crew on February 1, 2003 refocused NASA's attention on safety in the uncompromising environment of human spaceflight. My work in the many months that followed the accident have been centered on how to identify possible critical damage in the future, and then develop a means to go and repair such

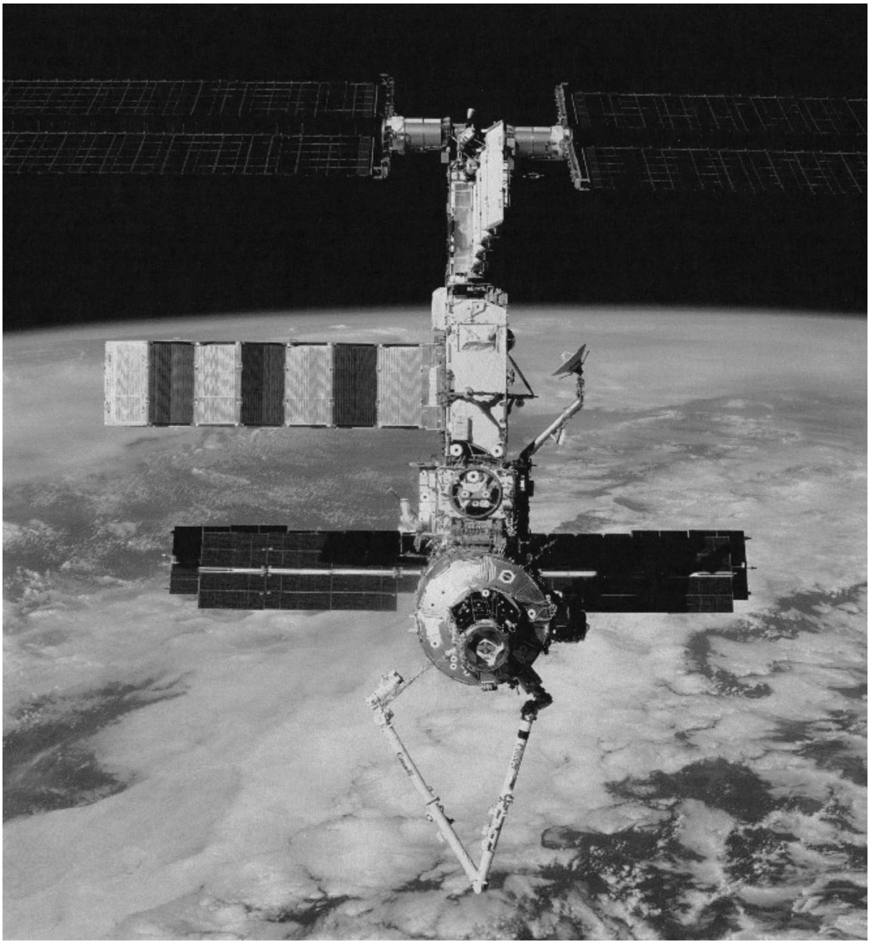

FIG. 3. The International Space Station upon undocking of the Space Shuttle Endeavor, following the successful completion of two complex spacewalks to assemble the Canadarm 2 (Space Station Robotic Manipulator System).

damage via EVA. Developing tools and techniques to perform delicate repairs on portions of the Space Shuttle vehicle that were never meant to be visited on-orbit (the belly of the Shuttle is very challenging to reach using the robotic arm, and obviously lacks the handholds typically required for EVA work) is extremely challenging. Moreover, identifying special materials that can be applied to damaged surfaces in the vacuum of space that in turn must withstand reentry temperatures of up to 3000 degrees F has proven extremely difficult. The can-do spirit that typifies NASA has provided some useful tools and techniques (11),

TABLE 1
The author's chronologic record of education, training and spaceflight

EVENT	DATES
Stanford University (Undergraduate)	1979–1983
Stanford Medical School	1983–1989
NASA-Ames Research Center Fellowship	1988–1989
Medical Internship, Brigham & Women's Hospital	1989–1990
Emergency Medicine Residency, Denver, CO	1990–1992
Began Training as an Astronaut Candidate	Aug-92
Space Shuttle Mission STS-66	Nov-94
Space Shuttle Mission STS-86	Sep-97
Space Shuttle Mission STS-95	Oct-98
Space Shuttle Mission STS-100	Apr-01
Space Shuttle Columbia Tragedy	Feb-03
Announcement of the Vision for Space Exploration	Jan-04
Space Shuttle Mission STS-118 (Anticipated)	Mar-07

but it remains unlikely that we would be able to repair damage of the sort that brought down *Columbia*. That said, substantial effort has gone into removing sources of debris from the External Tank that fuels the Shuttle on launch, such that we believe the likelihood of another Columbia-type impact is remote in the future.

STS-118 is currently slated for launch no earlier than the spring of 2007, most likely aboard the Space Shuttle *Endeavour*. The flight will feature 3 or 4 EVAs to continue assembly of the ISS. One of the crewmembers on the mission is Mission Specialist Educator Barbara Morgan, formerly STS-51L/*Challenger* astronaut Christa McCauliffe's backup. During the mission, widespread education outreach to young students around the country is planned.

In the aftermath of the accident, President George W. Bush redirected NASA towards a new Vision for Space Exploration (VSE) (12). After successful return of the Space Shuttle fleet to flight in July 2005, emphasis was placed on completing the ISS along with our international partners. The Space Shuttle will be retired from service at the end of 2010, to be replaced by a new Crew Exploration Vehicle and associated launch systems. This new vehicle will first ferry astronauts to and from ISS, commencing in 2012, and will ultimately transport astronauts back to the moon and later to Mars. A permanently tended outpost is anticipated on the moon, operated much as those on the Antarctic continent, with the goal of setting up radio telescopes free of earth radio "noise." The lunar outpost will also involve the study of how our solar system evolved, and how we might use local materials on the moon to support life and extend our presence even further in the cosmos (Mars, asteroids, beyond?).

Discussion

The exploration of space spans numerous fields of science and engineering, looking back towards earth—to track global environmental change, and develop a new technologies to benefit life here on earth—and also well beyond earth's orbit for discovery. The years ahead promise to be exciting, revelatory and inspirational as NASA leads missions back to the moon, on to Mars and destinations far beyond. All of the Space Shuttle missions mentioned above involved international crews, and the ISS itself is a shared multinational laboratory involving the United States and Russia, as well as the European, Canadian and Japanese space agencies. The benefits of our shared exploration go well beyond sharing the financial costs of this work, and it only makes sense that fulfilling the President's Vision for Space Exploration will involve continuing international participation as this mission of scientific discovery carries on.

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